Lesson 8

Equipment Associated with Scrubbing Systems

Goal

To familiarize you with the operation of equipment associated with scrubbing systems.

Objectives

At the end of this lesson, you will be able to do the following:

1. Briefly describe the operation of a centrifugal fan
2. Distinguish between forced- and induced-draft fans
3. List two maintenance problems associated with fans, pumps, ducts, and pipes in wet scrubbing systems
4. List three types of pipe materials used in scrubbing systems and the advantages and disadvantages of each
5. Briefly describe the function of quenchers
6. Describe three spray nozzle designs and identify two maintenance problems associated with nozzles
7. Describe the operation of three mist eliminators and identify two diagnostic monitoring techniques to ensure proper functioning of these components
8. List five important variables that should be monitored in scrubbing systems

Introduction

Many components comprise a complete scrubbing system. In previous lessons we have focused only on the operation of the scrubbing vessel itself. To fully understand the operation of a scrubber, it is important to have a basic knowledge of all the components of the system. For instance, fans and ducts are required to transport exhaust gas while pumps, nozzles, and pipes transport liquid to and from the scrubbing vessel. Water-recirculation and mist-elimination systems are also necessary. In addition, many systems use a quench ahead of the scrubber to humidify and cool the flue gases. Failure of any of these parts can cause problems for the entire scrubbing system. Finally, monitoring and recordkeeping are required not only to document but to prevent potential problems. This lesson presents an overview of the equipment associated with scrubbing systems—covering their operation and some typical maintenance problems.

Transport Equipment For Exhaust Gases and Scrubbing Liquids

Fans transport (push or pull) exhaust gases through ducts to and from the scrubber, while pumps transport liquids through pipes. Although not part of the scrubber chamber, both fans and pumps are essential to its operation.

Fans

Fans in scrubbing systems are usually centrifugal. In centrifugal fans, exhaust gas is introduced into the center of a revolving wheel, or rotor, and exits at a right angle (90°) to the rotation of the blades (Figure 8-1). Centrifugal fans are classified by the type and shape of blades used in the fan. The **forward-curved** fans use blades that are curved toward the direction of the wheel rotation. The blades are smaller and spaced closer together than the blades in other centrifugal fans. These fans are not usually used if the flue gas contains dust or sticky materials. They have been used for heating, ventilating, and air conditioning applications in industrial plants. **Backward-curved** fans use blades that are curved away from the direction of wheel rotation. The blades will clog when the fan is used to move flue gas containing dust and sticky fumes. They may be used on the clean-air discharge of air pollution control devices or to provide clean combustion air for boilers. **Radial** fans use straight blades that are attached to the wheel of the rotor. These fans are built for high mechanical strength and can be easily repaired. **Airfoil** fans use thick teardrop-shaped blades that are curved away from the wheel rotation. Airfoil fans can clog when handling dust or sticky materials.

Fan blades may be constructed of alloys or coated steel to help prevent deterioration when handling abrasive and corrosive exhaust gas. Radial fans are used most frequently for air pollution control applications; however, backward-curved fans are also used on wet scrubbing systems.

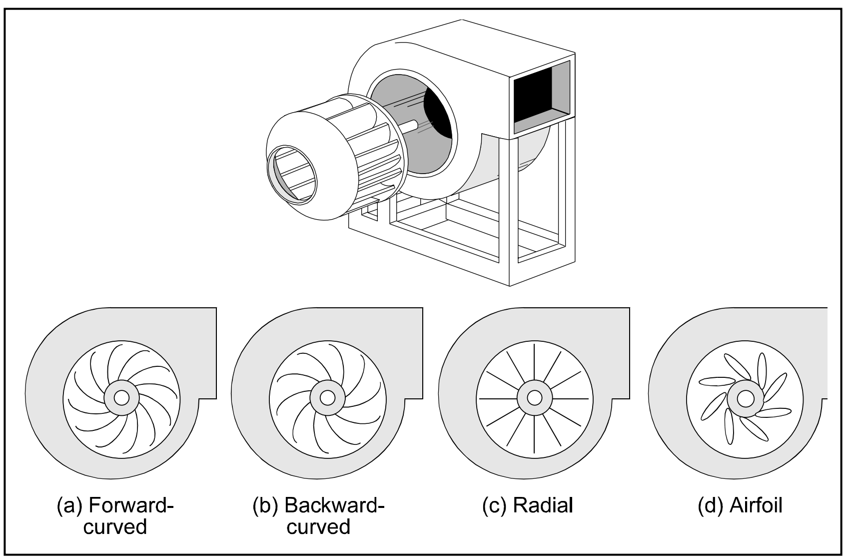

Figure 8-1. Types of centrifugal fans

Fans in scrubbing systems can be located before or after the scrubber. When located before the scrubber, they are referred to as **forced-draft, positive-pressure, or dirty-side** fans. These fans normally move dry air, but can move moist air depending on process conditions. They are subject to abrasion and solids buildup when dust concentration is high. Abrasion on the fan can be reduced by using special wear-resistant alloys, by using replaceable liners on the wheel, or by reducing fan speed (using a large fan that moves more slowly). The solids buildup can sometimes be controlled by using a spray wash to periodically clean the wheel. If dirty-side fans are used, a cyclone or knockout chamber can be placed before the fan to reduce dust concentration.

Fans located after scrubbers are always operated wet, and are called **induced-draft**, **negative-pressure, or clean-side** fans. These fans are subject to corrosion and solids buildup from mist escaping from the entrainment separator. Corrosion problems can result when the exhaust gas contains acid-forming or soluble electrolytic compounds, especially if the temperature of the gas stream falls below the dew point of these compounds. Corrosion can be reduced by using proper construction materials and careful pH control in the scrubbing system. Solids buildup can occur when the mist escaping from the entrainment separator contains dissolved or settleable solids. As the mist enters the fan, evaporation occurs and some solids deposit on the wheel. If the buildup on the wheel is uniform, no problems occur until the buildup starts to flake off, knocking the fan out of balance (Wechselblatt 1975). Keeping entrainment separators operating efficiently or using clean water sprays on the fan blades will help reduce solids-buildup problems.

Ducts

Ducts, or ductwork, transport exhaust gas to and from the scrubber. Ducts are carefully designed to keep pressure losses and, consequently, operating costs at a minimum. In general, this requires sizing the duct properly and minimizing the number of bends, expansions, and contractions. Sizing the duct to suit the exhaust stream velocity will also reduce the amount of dust that settles in the ductwork.

Abrasion and corrosion are common problems of ductwork. Abrasion is generally more severe on ductwork leading into the scrubber, while corrosion affects ductwork leaving the scrubber. Using proper construction materials or linings greatly reduces corrosion or abrasion. For example, ductwork can be lined partially or fully with brick (especially at elbows) to prevent erosion due to abrasion. For ductwork exiting the scrubber, special alloys resistant to acid attack should be used. Also, ductwork can be insulated to prevent acids in the flue gas from condensing.

Pumps

A wide variety of pumps are used to transport both the scrubbing liquid and the sludge. The proper choice of a pump depends on flow rate, pressure, temperature, and material being pumped. Electric-motor-driven centrifugal pumps are the pumps most frequently used in wet scrubbing systems (Calvert et al. 1972). In a centrifugal pump, the rotating impeller produces a reduction in pressure at the eye (center) of the impeller, causing liquid to flow from the suction pipe into the center of the impeller. The liquid is then forced outward along the blades and discharged generally at a 90 degree angle.

As with fans, abrasion and corrosion are the major maintenance problems associated with pumps in scrubbing systems. The impellers, housing and seals are subject to potential corrosion and abrasion problems. Abrasion is caused by solids buildup in the scrubbing liquid. Bleeding this liquid and removing the solids before recycling it back through the pump (or scrubber) will reduce pump wear. Most vendors suggest that the solids content be less than 15% (EPA 1982). Special alloys or rubber linings can also be used to help reduce abrasion and corrosion.

Pipes

Pipes transport liquid to and from the scrubber. As with pumps, pipes are susceptible to abrasion, corrosion, and plugging. Pipes can be made from a wide variety of materials to reduce these problems. Some advantages and disadvantages of pipe materials commonly used are given in Table 8-1.

To prevent solids from building up in or plugging the pipe, a liquid slurry velocity in the scrubbing system of 1.2 to 2.1 m/s (4 to 7 ft/sec) is recommended as a reasonable compromise (Czuchra 1979).

To test your knowledge of the preceding section, answer the questions in Part 1 of the Review Exercise.

Table 8-1. Pipe materials for scrubber systems—advantages and disadvantages

Material	Advantages	Disadvantages
Metals		
Cast iron	Flanged, threaded, or welded	Not resistant to corrosion
Steel	Inexpensive	
Stainless steel	Easy to cut and install on site	
Copper alloys		
Metal pipe linings		
Hard rubber	Good resistance to many strong acids and alkalis	Cannot be cut to size on site
Soft rubber	Resists abrasion	Must be precisely manufactured
Glass	Resists acid and alkali attack	Fragile
Thermoplastic	Resists corrosion	Not as abrasion resistant as rubber or stainless steel
PVC	Easily site-installed	
Polyethylene	Good resistance to temperature and stress	
Polypropylene		
Nonmetals		
Plastic	Resists corrosion	May not be as heat resistant as other materials
Fiberglass-reinforced pipe (FRP)	Resists chemical corrosion	Less abrasion resistant than rubber-lined pipe
	On-site installation	Operates at higher temperatures than a solid plastic pipe

Adapted from Calvert et al. 1972.

Quenchers

Occasionally, hot exhaust gas is quenched or cooled by water sprays before entering the scrubber. Hot gases (those above ambient temperature) are often cooled to near the saturation level. If not cooled, the hot gas stream can evaporate a large portion of the scrubbing liquor, adversely affecting collection efficiency and damaging scrubber internal parts. If the gases entering the scrubber are too hot, some liquid droplets may evaporate before they have a chance to contact pollutants in the exhaust stream, and others may evaporate after contact, causing captured particles to become reentrained. In some cases, quenching can actually save money. Cooling the gases reduces the temperature and, therefore, the volume of gases, permitting the use of less expensive construction materials and a smaller scrubber vessel and fan.

A quenching system can be as simple as spraying liquid into the duct just preceding the main scrubbing vessel, or it can be a separate chamber (or tower) with its own spray system identical to a spray tower.

Quenchers are designed using the same principles as scrubbers. Increasing the gas-liquid contact in them increases their operational efficiency. Small liquid droplets cool the exhaust stream more quickly than large droplets because they evaporate more easily. Therefore, less liquid is required. However, in most scrubbing systems, approximately one-and-a-half to two-and-a-half times the theoretical evaporation demand is required to ensure proper cooling (Industrial Gas Cleaning Institute 1975). Evaporation also depends on time - it does not occur instantaneously. Therefore, the quencher should be sized to allow for an adequate exhaust-stream residence time. Normal residence times range from 0.15 to 0.25 seconds for gases under 540°C (1000°F) to 0.2 to 0.3 seconds for gases hotter than 540°C (Schifftner 1979).

Quenching with recirculated scrubber liquor could potentially reduce overall scrubber performance, since recycled liquid usually contains a high level of suspended and dissolved solids. As the liquid droplets evaporate, these solids could become reentrained in the exhaust gas stream. To help reduce this problem, clean makeup water can be added directly to the quench system rather than adding all makeup water to a common sump (EPA 1982).

Spray Nozzles

Three different nozzle designs are used to produce a fine, cone-patterned spray. In the **impingement nozzle** (Figure 8-2), highly pressurized liquid passes through a hollow tube in the nozzle and strikes a pin or plate at the nozzle tip. A very fine fog of tiny, uniform-sized droplets approximately 25 to 400 μm in diameter is produced. Because there are no internal parts in the nozzle, it will not plug as long as particles larger than the opening are filtered out by a strainer. These nozzles are usually made of stainless steel or brass. In the **solid cone nozzle** (Figure 8-3), liquid is forced over an insert to break it up into a cone of fine droplets. Cones can be full, hollow, or square with spray angles from 15° to 140°. These nozzles can be made of stainless steel, brass, alloys, Teflon, and other plastic materials. The **helical spray nozzle** (Figure 8-4), has a descending spiral impingement surface that breaks up the sprayed liquid into a cone of tiny droplets. The cones can be full or hollow with spray angles from 50° to 180°. There are no internal parts, which helps reduce nozzle plugging. These nozzles can be made of stainless steel, brass, alloys, Teflon, and other plastic materials.

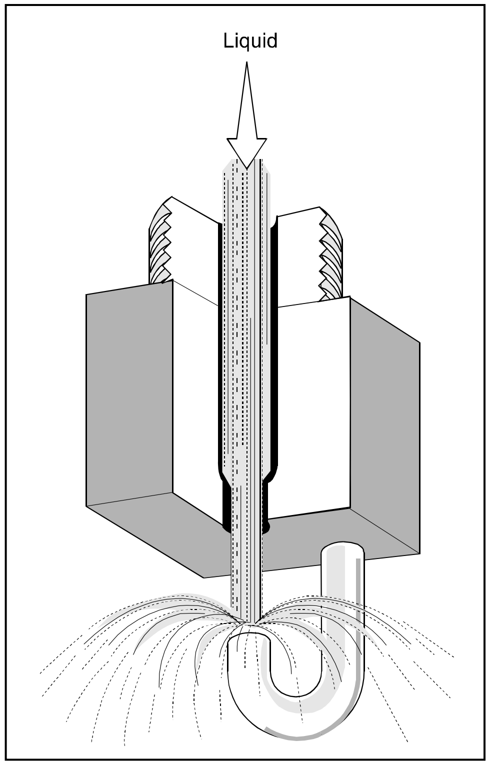

Figure 8-2. Impingement nozzle

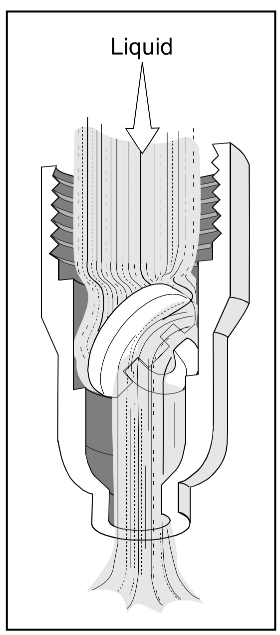

Figure 8-3. Solid cone nozzle

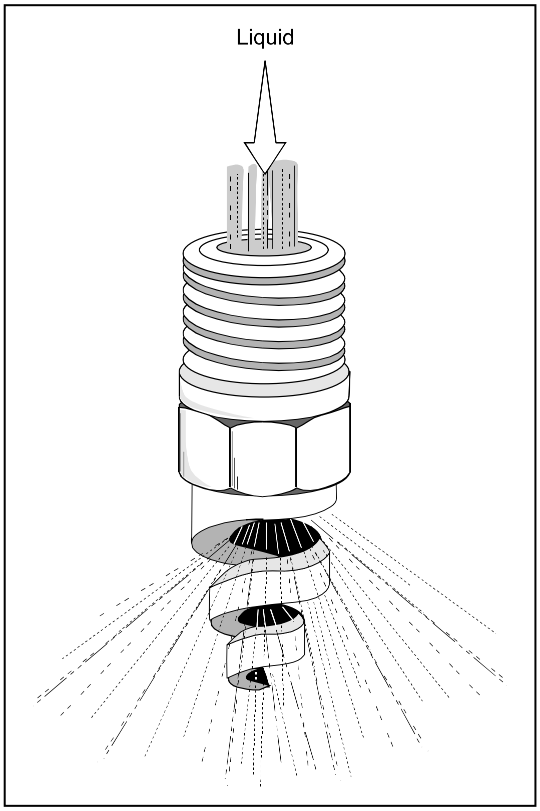

Figure 8-4. Helical spray nozzle

Different spray nozzles are appropriate for different scrubbing systems. Characteristics of the nozzles and sprays include the following:

1. **Droplet size** - In general, scrubbers using sprays to provide gas-liquid contact (such as in spray towers) require tiny, uniform-sized droplets to operate effectively. If the sprays are used merely as a method of introducing liquid into the vessel (such as in packed towers), then droplet size is not as critical.

2. **Opening size** - The actual opening in the nozzle will vary depending on the applications and the amount of liquid required. Openings range from 0.32 to 6.4 cm (0.125 to 2.5 in.).

3. **Spray pattern** - Nozzles are available that produce sprays in a number of geometric shapes such as square, fan, hollow cone, and full cone. Full-cone sprays are used to provide complete coverage of the areas sprayed.

4. **Operating mechanism** - Droplets can be produced by a number of methods such as impinging the liquid on a solid surface or atomizing the liquid using air.

5. **Power consumption** - In general, the finer the liquid droplet, the higher the power consumption.

Nozzle plugging is one of the most common malfunctions in scrubbers. Plugged nozzles reduce the gas-liquid contact and can also result in scale buildup on, or heat damage to, the scrubber parts formerly sprayed by the nozzle. Nozzle plugging can be most readily detected by observing the liquid spray pattern; however, if the nozzles are not easily accessible, a decrease in liquid flow is also a telltale sign (EPA 1982). Remedies include the following: (1) replacing the nozzle with one that is more open, (2) cleaning the nozzle frequently, (3) filtering the scrubbing liquid, (4) increasing the bleed rate and makeup water rates.

Another problem that can arise is reduced pressure in the spray header. This can cause a reduction in the spray angle (area covered) and an increase in the size of droplets produced.

Entrainment Separators

As mentioned in Lesson 1, the pollutant must first be contacted with the liquid, then the liquid droplets must be removed from the exhaust gas stream before it is exhausted to the atmosphere. Entrainment separators, also called **mist eliminators**, are used to remove the liquid droplets prior to exhausting gases to the atmosphere. Although the major function of an entrainment separator is to prevent liquid carryover, it also performs additional scrubbing and recovers the scrubbing liquor, thus saving on operating costs. Therefore, entrainment separators are usually an integral part of any wet scrubbing system.

Entrained liquid droplets vary in size depending on how the droplets were formed. Droplets that are torn from the body of a liquid are large (10 to 100 µm in diameter), whereas droplets that are formed by a chemical reaction or by condensation are on the order of 5 µm or less in diameter. Numerous types of entrainment separators are capable of removing these droplets. Those most commonly used for air pollution control purposes are cyclonic, mesh-pad, and blade separators.

The **cyclonic (centrifugal) separator**, which is commonly used with venturi scrubbers (see Lesson 3), is a cylindrical tank with a tangential inlet or turning vanes. The tangential inlet or turning vanes impart a swirling motion to the droplet-laden gas stream. The droplets are thrown outward by centrifugal force to the walls of the cylinder. Here they coalesce and drop down the walls to a central location and are recycled to the absorber (Figure 8-5). These units are simple in construction, having no moving parts. Therefore, they have few plugging problems as long as continuous flow is maintained. Good separation of droplets 10 to 25 µm in diameter can be expected. The pressure drop across the separator is 10 to 15 cm (4 to 6 in.) of water for a 98% removal efficiency of droplets in the size range of 20 to 25 µm.

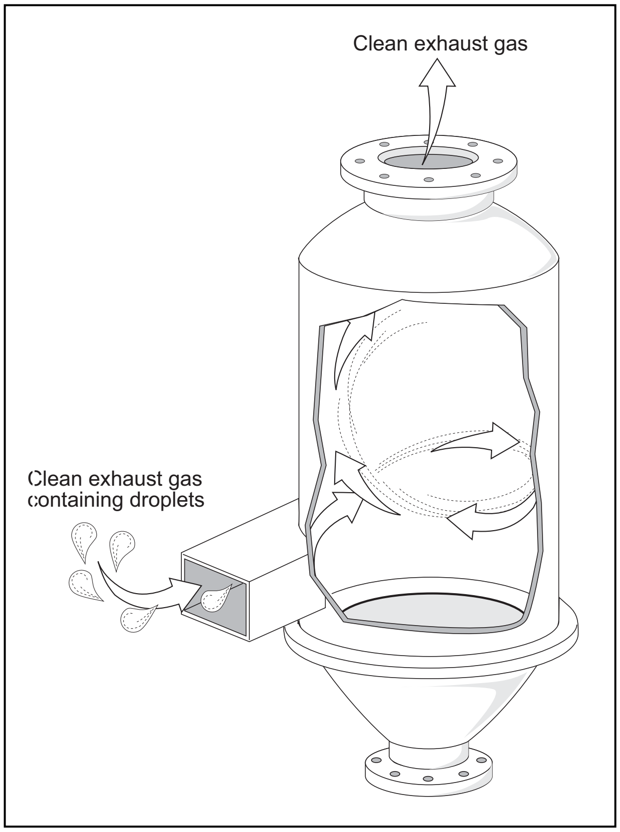

Figure 8-5. Cyclonic separator

In another design, wire or plastic is used to form mesh pads (Figure 8-6). These **mesh-pad separators** are approximately 10 to 15 cm (4 to 6 in.) thick and fit across the entire diameter of the scrubber. The mesh allows droplets to impact on the material surface, agglomerate with other droplets, and drain off by gravity. The pad is usually slanted (no more than a few degrees) to permit the liquid to drain off. Better than 95% collection of droplets larger than 3 µm is obtained with pressure drops of approximately 1.0 to 15 cm (0.5 to 6 in.) of water. (The pressure drop depends on depth and compaction of fibers). The disadvantage with mesh pads is that their small passages are subject to plugging. Periodically spraying pads from both below and above can remove some trapped material. However, spraying only from beneath will drive entrapped material further into the mesh, necessitating removal of the pads for cleaning or replacement (Schifftner 1979).

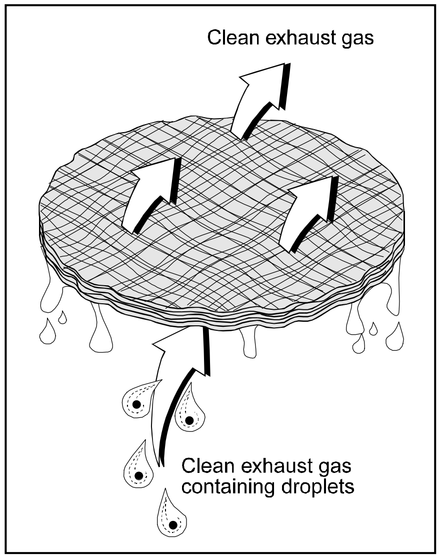

Figure 8-6. Mesh-pad separator

Blade separators can be of two types: chevron or impingement. In the **chevron separator** [Figure 8-7(a)], gas passes between the blades and is forced to travel in a zigzag pattern. The liquid droplets cannot follow the gas streamlines, so they impinge on the blade surfaces, coalesce, and fall back into the scrubber chamber or drain. Special features such as hooks and pockets can be added to the sides of these blades to help improve droplet capture. Chevron grids can be stacked or angled on top of one another to provide a series of separation stages. Pressure drop is approximately 6.4 cm (2.5 in.) of water for capture of droplets as small as 5 μm in diameter. **Impingement separators** [Figure 8-7(b)], being similar in shape to the common house fan, create a cyclonic motion. As the gas passes over the curved blades, they impart a spinning motion that causes the mist droplets to be directed to the vessel walls, where they are collected. Pressure drop ranges from 5 to 15 cm (2 to 6 in.) of water.

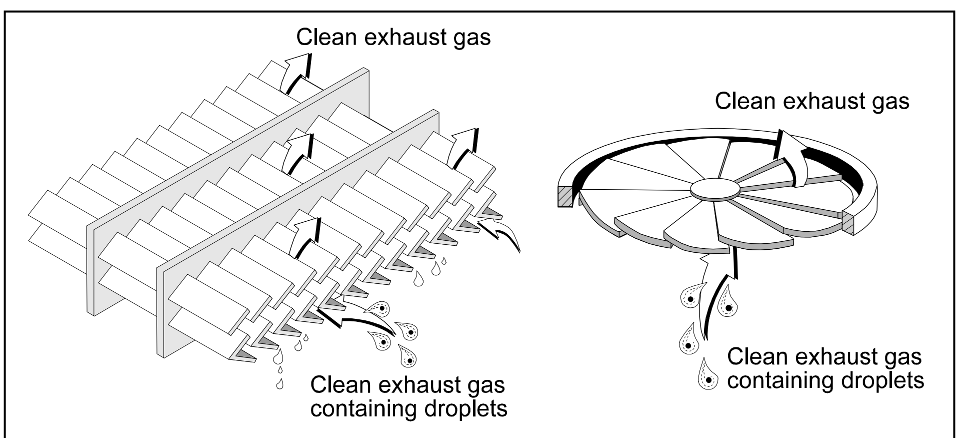

Figure 8-7. Two types of blade separators

The most important diagnostic aid in monitoring separator performance is the pressure drop. By measuring the pressure drop across the separator, the following problems can be identified (Wechselblatt 1975):

- A sudden decrease in pressure drop at constant load indicates that the separators have shifted out of place or are broken.
- An increase in pressure drop, even as little as 0.5 cm (0.2 in.) of water, is an indication of material buildup in the separator.

Another diagnostic measurement is gas velocity. Gas velocity through the separator must be kept below the maximum rate to avoid liquid reentrainment. Maximum velocities depend on operating conditions and the physical properties of the exhaust gas and liquid streams. The gas velocity should be kept below 3 m/s (10 ft/sec) for chevron separators, below 5 m/s (15 ft/sec) for mesh pads, and below 8 m/s (27 ft/sec) for impingement blades to reduce liquid carryover (Schifftner 1979). Table 8-2 summarizes some operating characteristics of entrainment separators.

Table 8-2. Typical operational characteristics of entrainment separators[1]

	Droplet size collected at 99%	Maximum gas velocity		Pressure drop	
Type	(µm)	m/s	ft/sec	cm H_2O	in. H_2O
Mesh pads	3.0	5	15	1.0-15	0.5-6
Cyclone	10-25	20	65	10-15	4-6
Blades					
Chevron	35	3	10	6.4	2.5
Impingement vane	20	8	27	5-15	2-6

1. Note: Values in this table are given as a general guide only. The collection efficiency for various droplet sizes depends on the gas velocity through the entrainment separators.

To test your knowledge of the preceding section, answer the questions in Part 2 of the Review Exercise.

Construction Materials

By now it should be obvious that scrubbing systems require special materials to prevent or reduce corrosion and abrasion. These are summarized in Table 8-3.

Table 8-3. Construction materials for wet scrubber components

Material	Properties/uses	Corrosion resistance
Metal		
Cast iron	High strength; low ductility; brittleness; hardness; low cost	Ordinary cast irons exhibit fair resistance to mildly corrosive environments; high-silicon cast irons exhibit excellent resistance in a variety of environments (hydrofluoric acid is an important exception); cast irons are susceptible to galvanic corrosion when coupled to copper alloys or stainless steels
Carbon steel	Good strength, ductility, and workability; low cost	Fair to poor in many environments; low pH and/or high dissolved solids in moist or immersion service leads to corrosion; properly applied protective coatings give appropriate protection in many applications; susceptible to galvanic corrosion when coupled to copper alloys or stainless steels
Martensitic stainless steel (410, 416, 420, 440c)	Chromium alloy, hardenable by heat treatment; typically used for machine parts; costs 2 to 5 times more than carbon steel	Good
Ferritic stainless steel	Chromium alloy, not hardenable by heat treatment; costs 2 to 4 times more than carbon steel	Good; better than martensitic stainless steel; resists stress corrosion; better chloride resistance than austenitic stainless steels
405	Modified for weldability	
430	General purpose, often used for chimney liners	Good resistance to atmospheric corrosion
442, 446	Used in high-temperature service	

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Table 8-3. *(continued)* Construction materials for wet scrubber components

Material	Properties/uses	Corrosion resistance
Austenitic stainless steel	Chromium and nickel alloy; not hardenable by heat; hardenable by cold working; nonmagnetic Types 201, 202, 301, 302, 303, 304, and 304L cost 3 to 5 times more than carbon steel; types 310, 316, 316L, and 321 cost 4 to 10 times more than carbon steel	Excellent; better than martensitic or ferritic stainless steel (except for halides)
201, 202	Nitrogen added, used as a substitute for 301 and 302	
301	Good hardenability	
302	General purpose	
304	General purpose	
304L	Modified for weldability	
310	Used in high-temperature service	
316	Used in corrosive environments	Superior corrosion resistance; good acid resistance; resistant to hot organic acids; good pitting resistance
316L	Improved weldability	
Nickel alloy	Good strength; costs over 10 times more than carbon steel	Excellent resistance in most environments; not resistant in strong oxidizing solutions such as ammonium and HNO_3
Inconel®[1]		Good resistance to stress corrosion
Monel®[1]		Good resistance to hydrofluoric acid
Hastelloy®[2] and Chlorimet®[3]		Excellent overall resistance
Titanium	High strength; light weight (60% that of steel); costs over 10 times more than carbon steel	Exceptional resistance at ambient temperatures; excellent resistance at other temperatures, except that crevice corrosion is possible in chloride solutions above 110°C (250°F)

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Table 8-3. *(continued)* Construction materials for wet scrubber components

Material	Properties/uses	Corrosion resistance
Nonmetal		
Glass and glass linings	Brittleness, subject to damage by thermal shock; can be protected against breakage by coating with polyester fiberglass	Good resistance to hydrochloric and dilute sulfuric acid
Brick linings		
Carbon brick	Used when fluorides are present; 540°C (1000°F) temperature limit	Acid resistant and abrasion resistant; also provides thermal protection for inner materials
Acid brick	870°C (1600°F) temperature limit	
Silicon carbide brick	1370°C (2500° F) temperature limit; high installation costs	
Porcelain and stoneware	Same properties but greater strength than glass; easily damaged by thermal shock	Good acid resistance
Rubber	Excellent mechanical properties and abrasion resistance; temperature limit of approximately 105°C (220°F)	Resistant to dilute acids, alkalis, and salts, but some oxidizing media will attach to it
Plastics	Less resistance to mechanical abuse, lower strength, and higher expansion rates; cannot be used where temperatures constantly exceed 105°C (220°F)	Excellent resistance to weak acids and alkalis; do not corrode and are not affected by slight changes in pH or oxygen content

1. Registered trademark of Huntington Alloys, Inc.
2. Registered trademark of the Stalite Divison of Cabot Corporation.
3. Registered trademark of the Duriron Company, Inc.

Sources: EPA 1982 and Perry 1973.

Monitoring Equipment

Having adequate equipment is imperative when monitoring the performance of a scrubber. Instrumentation on a wet scrubber can provide three distinct services:

- Obtaining *operational information* by recording daily data to help detect any problems or mis-operation that may occur

- Providing *operating input* for other devices to automatically operate some parts of the system
- Providing for safety by sounding alarms and/or releasing interlocks to protect both the operators and equipment

A monitoring system must be properly installed and maintained to provide reliable data. Monitors should be installed, operated, and calibrated according to the manufacturer's instructions. Because every scrubbing system is unique, the instrumentation and variables measured will vary from source to source. Table 8-4 lists monitors that are typically used in wet scrubbing systems.

Table 8-4. Monitoring equipment for wet scrubbing systems

Monitor	Measurements
Manometer	Measures pressure drop (inlet and outlet static pressure) across fan, scrubber vessel, and entrainment separator
Thermometer or thermocouple	Measures inlet and outlet temperatures of gas to and from scrubber Measures inlet and outlet temperatures of liquid to and from scrubber
Flowmeter	Measures liquid flow rate to scrubber Measures the amount of recycled liquid and bleed stream Measures flow rate of fresh makeup liquid to scrubber
pH meter	Measures pH level in chemical feed stream, scrubbing liquid, recycle liquor, and bleed stream
Ammeter	Monitors the current of the fans and pumps

For any of these monitors, high and/or low settings can be chosen so that if the set value is exceeded, an alarm sounds, a bypass is opened, or an emergency system is activated. For example, sources that scrub hot gases normally have a high-temperature alarm and/or an interlock system to automatically introduce emergency water or to bypass the scrubber if the high-temperature setting is exceeded.

Pressure Drop

One of the most useful operating parameters monitored on most scrubbing systems (especially venturis) is the static pressure drop (generally just referred to as pressure drop). To provide the most useful information, the pressure drop should be monitored across specific components, (i.e. the scrubber chamber and mist eliminator) instead of across the entire scrubber train. For example, measuring the pressure drop across the mist eliminator will give immediate indications of any plugging or particle buildup.

Static pressure is measured by simply inserting a tube (pressure tap) upstream and downstream of the scrubbing component. Figure 8-8 shows two types of tubes that can be used to measure pressure. Figure 8-8(a) illustrates using a small 1/4 inch copper tube, while Figure 8-8(b) illustrates use of an "s" type pitot tube (EPA 1983). The taps can be connected directly to indicating gauges such as manometers or magnahelics. The devices are located near where the measurements are being made. For information feedback to a central control room, the pressure taps can be connected to a differential pressure transmitter which sends the signal to a monitoring system in the control room. The biggest problems with measuring pressure in a scrubbing system are plugging of the taps and water condensing in the sample lines.

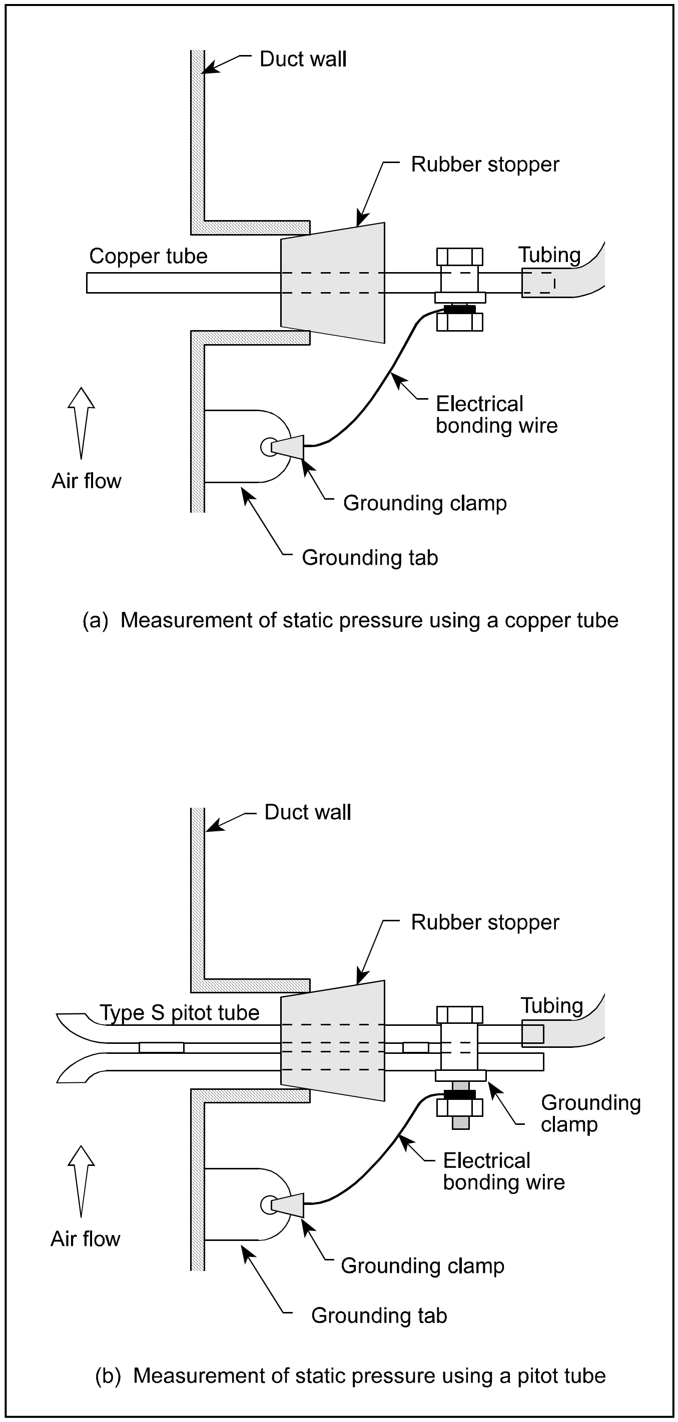

Figure 8-8. Two methods for measuring static pressure

Temperature

Temperature should be monitored both before and after the scrubber. Monitoring the scrubber inlet temperature is important to prevent high inlet gas temperatures. Excessive (higher than design) inlet temperatures could lead to excessive liquid loss due to evaporation, resulting in damage to scrubber components. Many scrubbers are constructed of fiberglass reinforced plastics (FRP) or have corrosion-resistant liners which have maximum gas temperature limits ranging from 200 to 400^oF. Emergency flush systems are included in many scrubbers to protect these components.

Measuring outlet temperatures is important for evaluating scrubber operation and protecting downstream equipment from excessive temperatures. Downstream from a wet scrubber, the gas should be saturated; saturation usually occurs at temperatures in the 150 to 160^oF range. High outlet temperatures can indicate poor liquid distribution or plugging of the liquid inlet (i.e. reduced heat transfer between liquid and gas).

Temperatures are measured using **thermocouples**. The main consideration with using thermocouples is that they should be installed in a location that provides an accurate representation of the gas stream temperature being measured.

Liquid Flow Monitors

Liquid flow monitors are used to indicate that flow rates are maintained in the design operating ranges. Liquid flow monitors can be used on the scrubber inlet as well as the makeup and/or blowdown from the scrubber.

The type of instrumentation used to measure flow depends on the size of the scrubber and characteristics of the liquid being monitored. Clean liquid streams can be monitored using *orifice* or *venturi meters*, *swinging vane meters* or a *rotameter*. All of these devices are in direct contact with the liquid stream and therefore subject to wear and buildup when suspended solids are present. *Ultrasonic* and *magnetic meters*, being non-contact devices, are not subject to these problems. However, they are more expensive, do not handle shock as well and require additional maintenance to obtain reliable data.

pH Monitors

The pH of various liquid streams is often manually monitored to prevent corrosion and scaling problems. At low pH levels (below 5) corrosion of metals will become a problem and at high levels, calcium and magnesium compounds can precipitate out of solution and cause scaling problems. The important areas where pH is monitored are the chemical and scrubbing liquor feed streams and the recycle liquor systems.

Occasionally, pH monitors are used to control the flow of alkaline reagent to scrubbing systems. Generally, pH monitors require a substantial amount of maintenance to remain operational. Most successful applications of pH meters for continuous pH monitoring employ sidestream monitors where only a small sample of the water flow is monitored rather than the total flow through the scrubber.

Recordkeeping

A comprehensive, site-specific recordkeeping system of both the design and operating history will enable personnel to better evaluate scrubber performance. Design records indicate the specific conditions under which the scrubbing system was built to operate. A comparison between design records and operating records can indicate whether operating parameters have changed significantly from the design conditions. Secondly, maintaining proper operating records establishes a good baseline of information to bracket normal ranges of operation.

There are certain data common to most scrubber types which should be included in any scrubber recordkeeping system. These data elements are listed in Table 8-5 (EPA 1983). Comparing these routinely measured parameter values to the baseline values can provide a very good indication of the performance of a scrubber. In addition, examination of these parameters over time can aid in the detection of component deterioration in the scrubber system. To be effective, recordkeeping should be conducted on a daily basis, if not once per shift.

Table 8-5. Scrubber operation data
Inlet Gas Temperature
Outlet Gas Temperature
Total Static Pressure Drop
Static Pressure Drop of Mist Eliminator
Liquor Feed Rate
Liquor pH
Water Makeup Rate
Fan Current
Fan RPM
Fan Gas Inlet Temperature
Nozzle Pressure
Pump Discharge Pressure
Recycle Bleed Rate
Chemical Addition Rate
Liquid Solids Concentration

Source: EPA 1983

It is recommended that whenever possible, the scrubber operation data be obtained using portable instruments (EPA 1983). Tap holes through which a measurement is made should be cleaned prior to every measurement to ensure that a partially or completely plugged hole does not result in an erroneous measurement. This, in fact, is one of the reasons that portable instruments should be used rather than fixed gauges. Often a reading from a fixed gauge will be recorded without checks to see that the gauge's tap hole is not plugged. Regardless of whether the instruments are fixed or portable, each must be calibrated at intervals which are at least as frequent as the manufacturer's specifications.

In addition to the scrubber data listed in Table 8-5, process data should also be recorded. Variations in process feed rate, capacity of the system and type of material being processed can affect the operation and/or efficiency of the scrubbing system.

Summary

Many components comprise any scrubbing system. All of the individual components must be properly designed and operated or else the scrubbing system may not function.

Fans and ductwork must transport the flue gas from the process through the scrubbing system and exhaust it through the stack. Also, pumps and associated piping carry the scrubbing liquid to and from the system. These components should be designed to minimize friction losses (resistance to flow) and to reduce their susceptibility to abrasion and corrosion problems.

Quenching systems are used to cool and humidify hot gases prior to entering the scrubber vessel. Cooling the hot gases protects the construction materials of the scrubber vessel and also reduces the amount of evaporation that could potentially occur in the scrubber vessel.

For both the quench and scrubber vessels, various spray nozzle designs are utilized. Two important factors in spray nozzle operation are the type of spray pattern produced and the ability to handle solids in the liquid spray. The impingement nozzle, solid core nozzle, and helical spray nozzles are described in this lesson.

Finally, any liquid droplets that become entrained in the gas stream must be removed by an entrainment separator (mist eliminator) before exhausting gas to the atmosphere. The three designs discussed in this lesson are cyclonic separators, mesh-pad separators, and blade separators. Properly designed and operated entrainment separators can help increase pollutant removal efficiencies. These devices must be carefully monitored to prevent potential plugging which could result in excess emissions or cause the system to shutdown.

A comprehensive monitoring and recordkeeping program will enable personnel to readily assess the effectiveness of the scrubbing system in addition to highlighting any potential component failures. The following variables should be monitored in scrubbing systems:

- Inlet and out gas temperatures
- Liquid flow rates
- Pressure drop
- pH levels in chemical bed streams
- The current flowing through fans and pumps

The pressure drop across the scrubber vessel and entrainment separator will give an indication of any potential plugging problems or flow variations. Temperature measurements across the scrubber or quencher can reveal any liquid distribution problems which are indicated by excess gas temperature. Measurement of scrubber liquid pH is important to prevent scaling and/or corrosion problems and also to maintain effective gas pollutant removal.

To test your knowledge of the preceding section, answer the questions in Part 3 of the Review Exercise.

Review Exercise

Part 1

1. What are the most popular types of centrifugal fans for wet scrubbing systems?
   a. Radial and forward-curved
   b. Radial and backward-curved
   c. Vane-axial fans and airfoil
   d. Forward-curved and backward-curved
2. Fans located before the scrubber are referred to as ____________________ fans.
   a. Positive-pressure
   b. Dirty-side
   c. Forced-draft
   d. All of the above
3. Fans located after the scrubber are always operated:
   a. Wet
   b. Dry
4. To reduce pressure losses in ducts, the number of ____________________ should be kept to a minimum.
   a. Bends
   b. Expansions
   c. Contractions
   d. All of the above
5. What is/are the primary maintenance problems(s) associated with fans?
   a. Abrasion
   b. Solids buildup
   c. Corrosion
   d. All of the above
6. True or False? In general, electric-motor-driven centrifugal pumps are the most frequently used pumps in wet scrubbing systems.
7. What area(s) of the pump is/are most susceptible to abrasion or corrosion?
   a. Impeller
   b. Housing
   c. Seals
   d. All of the above

8. What is a/(are) common problem(s) for pipes in most scrubbing systems?

   a. Abrasion
   b. Corrosion
   c. Plugging
   d. All of the above

9. True or False? Cast iron and steel pipes are very resistant to attack by corrosive materials.

Part 2

10. As the liquid droplets produced by the quench spray become ____________________, the quencher becomes more efficient in cooling the exhaust gas stream.

    a. Smaller
    b. Larger
    c. Rounder
    d. Heavier

11. Quenchers must be sized to provide an adequate ____________________ ____________________ for the exhaust gas, since evaporation does not occur instantaneously.

12. Quenching should be done with the ____________________ water available.

    a. Dirtiest
    b. Cleanest
    c. Highest-pH
    d. Lowest-pH

13. List five important characteristics of spray nozzles used in wet scrubbing systems.

    ____
    ____
    ____
    ____
    ____

14. True or False? Nozzle plugging is one of the most common malfunctions in wet scrubbers.

15. List five remedies for plugged nozzles.

    ____
    ____
    ____
    ____
    ____

16. Entrainment separators are used to:

    a. Prevent liquid carryover
    b. Recover scrubbing liquor
    c. Perform additional scrubbing
    d. All of the above

17. Cyclonic separators can remove liquid droplets as small as ____________________ in diameter.

    a. 0.01 μm
    b. 0.1 μm
    c. 1.0 μm
    d. 10.0 μm

18. In general, wire-mesh pads should be ____________________ to prevent plugging.

    a. Installed at a slant
    b. Sprayed from the bottom
    c. Sprayed from the top
    d. Sprayed from the top and bottom

19. True or False? Wire- or plastic-mesh pads are capable of removing smaller droplets than either cyclonic or blade separators; however, they are also more susceptible to plugging.

Part 3

20. Monitors are used in scrubbing systems to:

    a. Obtain operating information to trouble shoot potential problems.
    b. Provide input signals for other devices.
    c. Provide a safety feature by sounding alarm when design limits are exceeded.
    d. All of the above

21. True or False? The best manner to monitor pressure differentials is across individual components in a scrubbing system as opposed to the whole system.

22. Temperature is monitored in a scrubbing system to:

    a. Provide a safety feature by indicating potential high temperature.
    b. Prevent damage to scrubber components and equipment downstream from scrubber.
    c. Evaluate scrubber operation.
    d. All of the above

23. The primary problem(s) with measuring pressure differential is(are):

    a. The use of complicated and sensitive devices
    b. Difficulty of obtaining accurate readings
    c. Plugging of the pressure tap lines
    d. All of the above

24. True or False? It is impossible to measure liquid flow without having a device in contact with the liquid stream being measured.

25. In a good recordkeeping system, information on which of the following should be kept?

    a. Scrubber operating data
    b. Process operating data
    c. Design records
    d. a and b, only
    e. a, b, and c

26. True or False? In recording data from scrubbing system monitors/gauges, it is important to ensure that the gauge's tap hole is not plugged.

Review Exercise Answers

Part 1

1. **b. Radial and backward-curved**
   The most popular types of centrifugal fans for wet scrubbing systems are radial and backward-curved fans.

2. **d. All of the above**
   Fans located before the scrubber are referred to as positive-pressure, dirty-side or forced-draft fans.

3. **a. Wet**
   Fans located after the scrubber are always operated wet because the airstream is saturated with moisture.

4. **d. All of the above**
   To reduce pressure losses in ducts, the number of bends, expansions, and contractions should be kept to a minimum.

5. **d. All of the above**
   The primary maintenance problems associated with fans are:
   - Abrasion
   - Solids buildup
   - Corrosion

6. **True**
   In general, electric-motor-driven centrifugal pumps are the most frequently used pumps in wet scrubbing systems.

7. **d. All of the above**
   The areas of pumps that are most susceptible to abrasion or corrosion are the following:
   - Impeller
   - Housing
   - Seals

8. **d. All of the above**
   Common problems for pipes in most scrubbing systems are the following:
   - Abrasion
   - Corrosion
   - Plugging

9. **False**
   Cast iron and steel pipes are NOT very resistant to attack by corrosive materials.

Part 2

10. **a. Smaller**
    As the liquid droplets produced by the quench spray become smaller, the quencher becomes more efficient in cooling the exhaust gas stream. Smaller liquid droplets increase the surface area of the liquid, thereby facilitating evaporation.

11. **Residence time**
    Quenchers must be sized to provide an adequate residence time for the exhaust gas, since evaporation does not occur instantaneously.

12. **b. Cleanest**
    Quenching should be done with the cleanest water available.

13. **Opening size**
    Droplet size
    Spray pattern
    Operating mechanism
    Power consumption
    Five important characteristics of spray nozzles used in wet scrubbing systems are:

    - Opening size
    - Droplet size
    - Spray pattern
    - Operating mechanism
    - Power consumption

14. **True**
    Nozzle plugging is one of the most common malfunctions in wet scrubbers.

15. **Replace nozzle with one having a more open design**
    Clean nozzles frequently
    Filter the scrubbing liquor
    Increase bleed rate
    Increase makeup water rate
    Five remedies for plugged nozzles are:

    - Replace nozzle with one having a more open design
    - Clean nozzles frequently
    - Filter the scrubbing liquor
    - Increase bleed rate
    - Increase makeup water rate

16. **d. All of the above**
    Entrainment separators do the following:
    - Prevent liquid carryover
    - Recover scrubbing liquor
    - Perform additional scrubbing

17. **d. 10.0 µm**
    Cyclonic separators can remove liquid droplets as small as 10.0 µm in diameter.

18. **d. Sprayed from the top and bottom**
    In general, wire-mesh pads should be sprayed from the top and bottom to prevent plugging.

19. **True**
    Wire- or plastic-mesh pads are capable of removing smaller droplets than either cyclonic or blade separators; however, they are also more susceptible to plugging.

Part 3

20. **d. All of the above**
    Monitors are used in scrubbing systems to do the following:
    - Obtain operating information to trouble shoot potential problems
    - Provide input signals for other devices
    - Provide a safety feature by sounding alarm when design limits are exceeded

21. **True**
    The best manner to monitor pressure differentials is across individual components in a scrubbing system as opposed to the whole system.

22. **d. All of the above**
    Temperature is monitored in a scrubbing system to:
    - Provide a safety feature by indicating potential high temperature
    - Prevent damage to scrubber components and equipment downstream from scrubber
    - Evaluate scrubber operation

23. **c. Plugging of the pressure tap lines**
    The primary problem with measuring pressure differential is plugging of the pressure tap lines.

24. **False**
    Liquid flow can be measured without having the device in contact with the liquid stream. Ultrasonic and magnetic meters are non-contact devices.

25. **e. a, b, and c**
In a good recordkeeping system, information should be kept on the following:
    - Scrubber operating data
    - Process operating data
    - Design records

26. **True**
In recording data from scrubbing system monitors/gauges, it is important to ensure that the gauge's tap hole is not plugged.

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